

## **Life Cycle Waste Stream Estimates**

**August 2000**

Attached is an executive summary of a report prepared by Battelle Memorial Institute entitled "Sulfonated Perfluorochemicals: U.S. Release Estimate – 1997 Part 1: Life-Cycle Waste Stream Estimates", dated April 21, 2000. The objective of this work was to characterize and estimate the fluorochemical content of potential waste streams from both 3M manufacturing and supply chain facilities and from product usage.

Estimates in the report reflect conservative, worst case assumptions about the generation of wastes at supply chain facilities and 3M manufacturing locations in several respects. First, operator experience or engineering judgments often are used due to the unavailability of analytical data. Second, the report relies on 1997 sales figures to estimate customer and end user waste stream volumes. In the years subsequent to 1997, however, 3M has implemented significant manufacturing process improvements and has undertaken waste minimization measures as part of 3M's product stewardship program.

Finally and most importantly, PFOS and related compounds are described in the report in terms of "PFOS equivalents". "PFOS equivalents" is defined as the mass of PFOS molecules that would be formed after complete degradation of the fluorochemical products. PFOS equivalent(s) represent the weight of C<sub>8</sub>F<sub>17</sub>SO<sub>2</sub> present in a product. The waste stream estimates in this report are based on the assumption that each sulfonated perfluorochemical product and residual breaks down completely to PFOS in the year in which it was sold. This is a "worst-case" assumption. In fact, recent study results show that there has been no indication that PFOS undergoes any degradation from hydrolysis, photolysis, or biodegradation mechanisms. In all hydrolysis and photolysis studies, PFOS has not been detected as a degradation product in any conclusive experiment. These preliminary findings call into question the assumption of expected degradation of other fluorochemicals to PFOS. Relative to photolysis, the current data suggests a hypothesis that these materials will photolyze to carboxylate structures. These structures have much different properties than sulfonates in that they are much less bioaccumulative in ecological species.

**Sulfonated Perfluorochemicals:  
U.S. Release Estimation - 1997  
Part 1: Life-Cycle Waste Stream Estimates  
Final Report**

*for*

**3M Specialty Materials**

*prepared by*

**Battelle Memorial Institute  
505 King Ave.  
Columbus, Ohio 43201**

April 21, 2000

## Executive Summary

### Introduction and Objectives

The 3M Company is committed to a product stewardship policy that encourages safe and environmentally responsible practices in the development, manufacture, distribution, use and disposal of 3M products. The company has recently introduced a corporate initiative called Life Cycle Management (LCM) to assure an awareness of potential impacts at every stage of the life cycle. One step in LCM is to obtain good information on waste stream estimates and ambient environmental releases.

3M has been producing sulfonyl-based fluorochemicals (FCs) for over 40 years using the Electro-Chemical Fluorination (ECF) process. The basic building block of these products and the highest production volume FC manufactured by 3M is perfluorooctanesulfonyl fluoride (POSF). The chemical or enzymatic hydrolysis of POSF results in perfluorooctanesulfonate (PFOS). Based on current information from 3M, PFOS is believed to be the ultimate degradation product of the POSF molecule. It appears that destruction of PFOS only occurs through high temperature incineration. At this time, studies are underway to determine the degradation by-products of other POSF-derived fluorocarbons. Initial results indicate that ultimate degradation rates are variable, with some fluoropolymers apparently stable for hundreds of years.

The Release Estimation Task is based on 1997 sales data for the U.S. Product portfolio changes, manufacturing process improvements, and minimization of manufacturing wastes and releases will dramatically change the results of this 1997 estimation in coming years.

The Release Estimation Task has been subdivided into two discrete phases. The objective of phase one is to characterize potential FC waste streams, while phase two is designed to estimate releases to the ambient environment. Both phases will consider the full life cycle of FC products, including: manufacturing of compounds by 3M, distribution and conversion stages (supply chain) where the FCs are sold and/or incorporated into products, commercial and residential consumer use of the products, and waste disposal or recovery of used products. Phase one, life cycle waste stream estimation, is addressed in this report. The specific objectives of phase one are:

- to make reliable estimates of the most important FC waste streams that may result in releases leading to human and ecological exposure,
- to perform screening for identifying the most important FCs based on pounds of PFOS-equivalents and FC solids,
- to provide waste stream estimates that will serve as the basis for modeling of potential FC releases from landfills and wastewater treatment plants (WWTPs), and
- to provide waste stream estimates that will serve as the basis for further analysis of fate, transport, and exposure, including multimedia fate modeling using the fugacity principle.

## Final Report

The results from phase one can be used for a variety of purposes in other tasks in 3M's overall program. Some examples of the potential uses of waste stream estimates by other tasks include: determining locations for empirical sampling, selecting highest priority FC products for measurements of physical-chemical properties, and selecting treatment facilities and associated FC input estimates for modeling of ambient environmental releases.

The waste stream estimates in this report are expected to change as additional information is collected. Estimates used in this report are based on conservative, worst case assumptions about the generation of wastes at supply chain facilities and 3M manufacturing locations, and are often based on operator experience or engineering estimates rather than laboratory tests. As such, the estimates can result in wide ranges in waste stream calculations.

### Screening for Key FC Products

During an initial review of data supplied by 3M for 72 FC products in six different business units, a screening process was developed to narrow this list to the products considered key for a waste stream evaluation from a total 3M standpoint in the U.S. The screening process used 1997 sales data for the U.S. to identify 19 key products that contribute > 1% of total 3M FC solids or > 1% of total 3M PFOS-equivalents. The 19 chemically different products selected, which include 21 product codes, collectively represent approximately 87% of FC Solids and 88% of PFOS-equivalents for the total 1997 sales of FC compounds. The 21 screened product codes are as follows:

| <u>Business Unit</u>         | <u>Product Codes</u>                                        |
|------------------------------|-------------------------------------------------------------|
| Aftermarket/Consumer Apparel | (FC-129, FC-430, FC-228, FC-1861)                           |
| Carpet                       | (FC-3573/FC-3573N, FC-248, FC-461)                          |
| Home Textiles                | (FC-364, FC-365, FC-398, FC-1367)                           |
|                              | (FC-247, FC-248, FX-1380, FC-280, FX-1801, FC-1861, FC-461) |
| Paper and Packaging          | (FC-807, FC-809, FC-807A, FC-845)                           |
| Performance Chemicals        | (FC-129, FC-170C, FC-430, FC-138)                           |

The three products with the largest quantity of PFOS equivalents sold in 1997 are FC-807, FC-809, and FC-1367.

Since the screening process involved identification of products sold in the U.S. during 1997 that contribute > 1% of total 3M FC solids or > 1% of total 3M PFOS-equivalents, Lightwater™ was not determined to be one of the 19 key products. Thus, these products are not being evaluated as part of this program.

### 3M Manufacturing Wastes

In a continuing effort to characterize wastes from manufacturing, Decatur process engineers have provided estimates of FC waste streams for the 3M manufacturing facility

## Final Report

at Decatur, Alabama. Engineering calculations, 3M information systems, and air emission models were used to identify and quantify current waste streams. 3M manufacturing wastes are primarily associated with a few key steps in the early stages of POSF manufacturing and purification and therefore are not attributed to any one product. Based on the information from Decatur engineers, it is likely that the Decatur manufacturing facility is a substantial source of PFOS equivalents released to the environment. However, ongoing engineering activities at the Decatur facility have reduced FCs in water effluent from the levels for 1997. Total annual wastes in wastewater and solid waste from the Decatur facility before treatment are approximately 1,088,000 pounds of PFOS equivalents, but a little over half of these wastes are disposed of by high-temperature incineration, resulting in no release of sulfonated perfluorochemicals. Comparison of the results from sampling done in early and late 1998 indicates that the quantity of PFOS discharged to the river after treatment has declined, due to upgrades in the wastewater treatment system and administrative changes in off-spec product discharge procedures.

### Aftermarket/Consumer Products

Four supply chain facilities account for all of the 1997 sales of key Aftermarket/Consumer products. The key FC products purchased by one or more of these four primary Aftermarket/Consumer manufacturers, in decreasing quantity of PFOS equivalents are FC-1861, FC-138/228, and FC-129.

The majority of the PFOS equivalents in wastewater generated by the four manufacturers using key Aftermarket/Consumer products are associated with Mix Tank operation. The highest estimated waste generation value into wastewater from this process is 6.2%, which is associated with process startup and shutdown.

Generation of FCs in wastes during use of spray can products by residential consumers depends on transfer efficiency, size and shape of the object being coated, and accuracy of the applicator. It is roughly estimated that transfer efficiency across all sizes and shapes of applications is 66%, which means that 34% of product expelled from the can is initially lost as waste to the air, with the potential for deposition.

Spray cans used to apply treatments in the home are expected to retain a small fraction of the product material at the time of disposal. Based on information for non-food spray cans in general, up to 12.5% of the original contents may remain in spray cans at the time of disposal. Bulk product containers for commercial care are expected to retain 2.9% of product, which is wasted during container cleaning and disposal. It is estimated that 34% of the spray can containers will be recycled, with residual product material in the can lost to wastewater. Containers that are not recycled are sent to landfills.

Carpets with commercial care FC treatments used by professional carpet steam cleaners are expected to show similar wear patterns to carpets with mill applied treatments. Thus, it is expected that 50% of the FC treatment will be removed over the nine-year life of the carpet due to walking and vacuuming, while an additional 45% of the FC treatment will be removed in steam cleaning throughout the carpet life.

## Final Report

Garments treated with home-applied products are assumed to wear in a similar manner to textile mill applied treatments. Thus, 73% of these treatments are expected to wash off during garment cleaning over a two-year life span.

Any remaining FCs on coated products at the end of their useful life are assumed to be disposed of at the national averages for landfill disposal (83%) and incineration (17%).

### Apparel Products

Seven supply chain manufacturers purchased the greatest quantities of PFOS equivalents for Apparel products during 1997. These customers account for 56%, 73% and 41% of 1997 product sales of FC-3573, FC-248, and FC-461, respectively. The majority of the PFOS equivalents sold to these seven supply chain customers are associated with FC-248.

The majority of the PFOS equivalents in wastewater generated by the seven manufacturers using key Apparel products are associated with the processes Product Distribution and Application. The highest estimated percent loss into wastewater from these processes is 9.3%, which is associated with application to leather products. The majority of the PFOS equivalents in solid waste from the seven manufacturers using key Apparel products are associated with the process of cutting and sewing garments, which involves an estimated loss to solid waste of 10% for both cloth and leather garments.

Assuming that consumers own and regularly use FC-treated cloth apparel for an average of two years and launder the garment an average of every two weeks, 3M laboratory tests suggest that 73% of the initial treatment will be wasted during consumer laundering over the total life span of the garment. It is anticipated that the vast majority of this waste is in wastewater and not in dryer lint. Leather products, including any remaining treatment, are disposed of after use. Based on national averages for municipal waste, 83% of apparel and leather products will be sent to landfill and 17% will be incinerated.

### Carpet Products

Six supply chain customers purchased the greatest quantities of PFOS equivalents for Carpet products during 1997 (> 70% of key Carpet product sales). The key FC products purchased by one or more of these manufacturers, in decreasing quantity of PFOS equivalents are FC-1367, FC-365, and FC-364/FC-398. The majority of PFOS equivalents in wastes generated by these manufacturers are in wastewater. The largest waste generation value for PFOS equivalents in wastewater from these manufacturers is an estimated 25%, which is from the carpet fiber dyeing process (FC-365 and FC-364) and co-application to finished carpet (FC-1367). However, less than or equal to 5% of FC-1367 is co-applied.

The quantities of PFOS equivalents removed from carpets made in 1997 during use by the end consumer are larger over the total life of the carpet than the quantities wasted during the supply chain manufacturing processes in 1997. However, the wastes from end use customers during carpet cleaning, foot traffic, and vacuuming are spread over the 12-

## **Final Report**

year average life of a carpet and the residential end use customers are distributed throughout the U.S. approximately according to number of households in an area. The FC Carpet product contributing the most PFOS equivalents to waste during the end use stage is the one sold in the largest volume, which is FC-1367. Losses of PFOS equivalents in wastes from FC Carpet products during the end use stage are about equally distributed between wastewater (47%) and solid waste (53%).

### **Home Textiles Products**

Nineteen supply chain customers were identified as the locations with the highest sales receipts of PFOS equivalents for Home Textiles products during 1997. These customers account for between 21% and 97% of the priority Home Textile products, depending on the product examined.

The key FC products purchased by one or more of the 19 primary Home Textiles manufacturers, in decreasing quantity of PFOS equivalents are FC-247, FX-1801, FC-824 and FC-138 (equal amounts), FC-248, FC-280, FC-461, and FC-1861. Loss of PFOS equivalents into wastewater from the manufacturers making woven products is estimated to be a maximum of 9.9% from Unused or Non-Recovered Bath Mix following application. Supply Chain facilities producing non-woven products either pad apply product or add product directly to an extrusion mix. As was the case for woven products, the highest estimated waste generation value from these processes is 9.9% associated with pad application. Loss of PFOS equivalents in solid waste from the manufacturers making woven products is estimated to be a maximum of 4.9% from one of four processes.

Based on data for production of clothing, it is estimated that 10% of the PFOS equivalents used in woven fabrics for upholstery (FC-247, FX-1380) are lost in solid waste during cutting and sewing.

Nonwoven medical fabrics and HEPA filters are typically single use products that are used for a very brief period and then disposed of, so the majority (>99.999%) of the PFOS equivalents will go with the solid waste.

It is assumed that used Home Textile products are disposed of according to the national averages for municipal solid waste sent to incinerators (17%) and landfills (83%).

### **Paper and Packaging Products**

Six supply chain customers purchased the greatest quantities of PFOS equivalents for Paper and Packaging products during 1997 (> 70% of key Paper and Packaging product sales). The key FC products purchased by one or more of these paper manufacturers, in decreasing quantity of PFOS equivalents are FC-807, FC-809, FC-845, and FC-807A. PFOS equivalents in wastes generated by these paper manufacturers are primarily in the form of wastewater from the make down tank. Approximately 1% of the total run volume is lost as wastewater.

Wastes of FCs during converting and end use of treated paper products are very small. During the making of paper products, converters dispose of about 3% of input paper

## **Final Report**

products treated with FCs as solid waste. Extremely small percentages of PFOS equivalents are expected to adhere to package contents during the end use stage. It is estimated that a very small amount is potentially transferred from the package to the contents. Studies are underway to confirm these transfer rates.

Based on the 1997 national averages for solid waste disposal of paper products, about 17% are incinerated. FCs in paper products sent to high-temperature incinerators are completely destroyed. Scotchban™ treated end-products are not recovered for recycling as part of solid waste recycling programs. Therefore, all products not incinerated are expected to go directly to municipal waste landfills. This means that 83% of the product material remaining after consumer use will be sent to a landfill as solid waste.

### **Performance Chemical Products**

Eight supply chain customers purchased the greatest quantities of PFOS equivalents for Performance Chemical products during 1997 and account for all of the 1997 sales of key Performance Chemical products. The key FC products purchased by one or more of these eight manufacturers, in decreasing quantity of PFOS equivalents, are FC-129, FC-430, FX-12, and FC-170C.

Performance Chemical products are used in a wide variety of products and industries. Based on surrogate waste stream estimates compiled from information on other product lines and available data sources, the highest estimated waste generation value from processes in supply chain facilities for key Performance Chemical products is 7.7%. This waste is associated with wastewater from the startup and shutdown of mixing and blending operations.

Industrial and consumer practices govern the use of Performance Chemical products. Varying quantities of FCs are lost in waste streams during application and use. Uses include surfactants for paints and coatings, additives for cleaners and protectors, and insecticides. FCs are disposed of with the product, according to national averages.

Although the quantities of FC solids and PFOS-equivalents in AFFF products sold in 1997 are less than the one percent used for screening key products to evaluate in this document, the method of use as fire fighting foams involves potentially direct release to the environment. Thus, these products will be evaluated as part of a separate 3M task.

### **Summary**

The five key FC products sold in the largest quantity in declining order of PFOS equivalents are FC-807, FC-809, FC-1367, FC-845, and FC-247. FC-807, FC-809, and FC-845 are part of the Paper and Packaging Business Unit. FC-1367 is part of the Carpeting Business Unit. FC-247 is part of the Home Textiles Business Unit.

The two largest percent waste generation values for PFOS equivalents from processes at supply chain facilities for the 19 key products evaluated are associated with the Carpeting, Apparel, and Home Textiles Business Units. The processes with the largest percent waste generation value across all of the supply chain facilities handling key FC

## Final Report

products is an estimated 25% during the dyeing process for carpet fiber and an estimated 25% during co-application on carpets. However, less than or equal to 5% of FC-1367 is co-applied. The processes with the second largest percent waste generation value across all of the supply chain facilities handling key FC products is an estimated 10% in solid waste during the Cutting and Sewing process for garments and upholstery, respectively, in the Apparel and Home Textile supply chain facilities.

The three business units with the largest percent waste generation value for PFOS equivalents in wastes from the End Use/Disposal Stages of the life cycle for the 19 key products in all supply chain facilities are Aftermarket/Consumer, Paper and Packaging, and Performance Chemicals. When the key products are evaluated for each of these three business units as a whole, greater than 85% of the PFOS equivalents in wastes are generated during the End Use/Disposal Stages (includes waste streams from consumer end use and disposal).

The inventory data provide estimated quantities of PFOS equivalents in air, wastewater, or solid waste for site-specific locations throughout the supply chain stage of the life cycle. PFOS equivalent waste generation estimates in waste streams were calculated at 48 of the supply chain locations handling the greatest quantities of the 19 key FC products.

A summary of the life cycle, waste stream estimates based on 1997 sales of 3M FCs in the U.S. is shown in the table below. The waste stream estimates are presented as PFOS equivalents, which do not include residuals that may be in the products. The U.S. waste stream estimates are broken down by life cycle stage (e.g., 3M manufacturing, supply chain facilities, end use consumers, and disposal) and form of waste (e.g., air, wastewater, or solid waste). These estimates are an indication of level of PFOS in waste streams, but not human or ecological exposure levels.

Although the waste stream estimates in the following summary table can give an indication of the potential for environmental releases, most of the wastewater and solid waste indicated in the table are sent, respectively, to a wastewater treatment plant (WWTP) or a landfill and not directly to the environment. One exception is the estimates for the Decatur 3M manufacturing facility, where estimates are provided for wastewater before treatment and water releases to the environment after treatment by an industrial wastewater treatment plant (IWTP).

# Final Report

## Summary of Estimated<sup>(1)</sup> FC Waste Streams Based on 1997 Sales in the U.S. (PFOS equivalents<sup>(2)</sup> in lbs./yr)

| 3M Business Unit (BU)                     | Waste Stream               | Supply Chain Processing (3M customers) | End Use (Consumers) | Disposal  | BU Total  | 3M Mfg. Waste Streams <sup>(3,4)</sup> | 3M Mfg. Release <sup>(5)</sup> |
|-------------------------------------------|----------------------------|----------------------------------------|---------------------|-----------|-----------|----------------------------------------|--------------------------------|
| Aftermarket/ Consumer                     | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Apparel                                   | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Carpet                                    | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Home Textiles                             | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Paper and Packaging                       | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Performance Chemicals                     | Airborne                   |                                        |                     |           |           |                                        |                                |
|                                           | Wastewater                 |                                        |                     |           |           |                                        |                                |
|                                           | Solid Waste                |                                        |                     |           |           |                                        |                                |
|                                           | % of BU Total              |                                        |                     |           |           |                                        |                                |
| Total for All BUs Combined <sup>(6)</sup> | Airborne                   | 2,600                                  | 3,300               | 0         | 5,900     | N/A <sup>(7)</sup>                     | 19,000                         |
|                                           | Wastewater                 | 110,000                                | 180,000             | 350       | 290,000   | 51,000                                 | 10,000                         |
|                                           | Solid Waste <sup>(8)</sup> | 59,000                                 | 200,000             | 1,300,000 | 1,500,000 | 1,037,000                              | -                              |
|                                           | Landfill                   |                                        |                     |           |           | 380,000                                | N/A <sup>(9)</sup>             |
|                                           | Incineration               |                                        |                     |           |           | 657,000                                | N/A <sup>(10)</sup>            |

(1) Estimates used in this report are based on conservative, worst case assumptions about the generation of wastes at supply chain facilities and 3M manufacturing locations, and are often based on operator experience or engineering estimates rather than laboratory tests. As such, the estimates can result in wide ranges in waste stream calculations.

(2) Assumes eventual degradation of all sulfonated perfluorochemicals to PFOS. PFOS equivalents do not always include all residuals that may be present in the products.

(3) These estimates are based on manufacturing data for 1997-1999.

(4) 3M manufacturing emissions are primarily associated with a few key steps in the early stages of POSF manufacturing and purification and therefore are not attributed to any one product.

(5) These values are estimates of release to the environment from manufacturing and are shown for reference.

(6) Totals for BUs are rounded to two significant figures

(7) Not Available. Available data do not allow the estimation of airborne discharges prior to treatment.

(8) Solid releases from manufacturing are subcategorized into landfill waste and incinerated waste. Production and use data are not subcategorized.

(9) Not Available. Releases from common treatment processes such as landfills will be estimated as part of phase 2 of the release estimation task.

(10) FCs undergo complete thermal destruction during high-temperature incineration, so no FCs are released to the environment in emissions from the incinerator.

## Glossary

**Customer:** Company or facility that accepts product shipped from 3M manufacturing operations and performs processing for further use. Processing done by customers can include dilution or other mixing, application, re-packaging, etc. Both 3M clients and contract manufacturers are considered customers, however, distributors are generally not considered customers.

**End-Product:** Finished goods used by consumers (usually the general public). Examples of end-products include treated garments, french-fry containers, installed carpeting, stain-resistant furniture, spray cans, alkaline cleaners, etc.

**Effluent:** Liquid release. Waste carried in a liquid media from final treatment as an ambient discharge.

**Emissions:** Generally used as a synonym for release, emissions are wastes that leave final treatment and are discharged to ambient media. Typically the media to which wastes are discharged is specified, e.g. airborne emissions.

**End-Product Mixture:** Generally applicable to liquid end-products only, the end-product mixture is the combination of chemicals required to produce the desired end-product. In many cases end-products contain a mixture of sulfonated perfluorochemicals, solvents, and other active and inactive ingredients. End-product mixtures are assumed to be uniform mixtures of all ingredients. An example of an end-product mixture is the home care fabric protector (Red Can) mixture which contains 1.5% (by weight) FC-1860.

**Product (or Product Material):** Material shipped from 3M sulfonated perfluorochemical-manufacturing facilities (e.g. Decatur, AL) to customer facilities (customers include both 3M clients and contract manufacturers). Products are typically referred to using product codes, such as FC-807, FX-1801, FC-170C, etc.

**Release:** The discharge of sulfonated perfluorochemicals or end-products containing these chemicals to the ambient environment. For example, industrial wastewater discharges that are further treated are not considered releases. However, industrial stack airborne emissions that are discharged to the ambient air are considered releases.

**Wastewater:** Waste carried in a liquid media from the point of discharge to further treatment prior to release into ambient media. This includes both industrial and residential liquid waste prior to treatment.

**Waste Stream:** Waste generated at any stage of the life cycle that is transferred to a treatment operation prior to release to the environment. Part 1 of the Release Estimation report estimates sulfonated perfluorochemical waste streams.